

Integrated quantification of forest total economic value

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ABSTRACT

Climate change and biodiversity loss represent major challenges for both developing and developed countries. It is necessary to demonstrate that conservation efforts designed to address such challenges, such as national parks or nature protection areas, are not at odds with regional development goals. Forests' carbon sequestration is well known, but they also provide a range of other ecosystem services. Additionally, they support local socio-economic dynamics such as cultural value and sustainable tourism. However, ecosystem assessments are time and resource consuming endeavors, and, in order to encourage consideration of forest conservation, a methodology applicable to any natural forest type in the world was created that allows quick total economic value (TEV) estimations. Existing methodologies and the scientific literature were reviewed. Given the prominence of carbon markets, this estimation is divided into carbon sequestration, other ecosystem services, and socio-economic impacts, which are combined into one monetary value. This tool is capable of offering policy makers, companies, and communities a quick assessment of a forest's TEV, thus it is a step towards the complete valuation of various land uses and ecosystems often found in nature protection areas. Following the results, the tool's contribution to the literature and future research needs are discussed.

1. Introduction

Mitigating the worst impacts of climate change involves changing behaviors and making better decisions. The development of policy tools to measure the total economic value (TEV) of the environment is necessary to inform both public and private actors of the nonmarket benefits and tradeoffs that always exist in projects, programs, and policies. TEV tools may benefit environmental assessment (EA) as well as conservation and preservation efforts, such as national parks and nature protection areas (NPA), which have been met with reluctance due to lack of understanding surrounding the value that such ecosystems provide. Promisingly, initiatives such as mandatory carbon markets and carbon taxes, as well as voluntary carbon and biodiversity markets have emerged that have led to renewed interest in conservation (Hamrick and Gallant, 2017; ICAP, 2017; Madsen et al., 2010; World Bank et al., 2016).

Forestry represents a major opportunity to combat climate change. Carbon sequestration methods have improved markedly since their inception (Kägi and Schöne, 2005), but carbon sequestration accounting, or carbon projects that consider secondary benefits (i.e., ES or social benefits) are labor intensive and require quality assurances (US

GAO, 2008). This may discourage its wider uptake by both public and private actors, a tool capable of offering an initial estimate could help fill this gap and encourage more widespread environmental accounting. The aim of this work is to measure the TEV of forests and integrate these values into one monetary number capable of assisting decision-making regarding land use, land use change, and forestry (LULUCF). The aim was to develop a tool capable of offering quick estimations of carbon sequestered, additional ecosystem services, and the means by which socioeconomic impacts could be assessed. Since carbon markets continue to outnumber additional benefit markets, such as biodiversity markets, the methodology developed here set aside carbon sequestration from the numerous other ecosystem services (ES) provided by forests. Thus, users can assess those benefits relevant to the market they are pursuing or their objectives. The hope being that this tool further facilitates the incorporation of ecological and social tradeoffs into decision-making by highlighting the quality and quantity of such values in forestry projects in monetary values via an user-friendly integrated method. Just as importantly, how much the tool could be used to show how much value could be lost if an alternative land use is chosen for a forest (e.g., an industrial park), which could help estimates of cost-benefit analysis.

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Following a brief review of the components of the methodology presented here (forest carbon accounting, the ES approach, and regional added value – RAV), the materials and methods section describes the development of a tool to quickly assess the TEV of forests. The results discuss its three parts as well as its strengths and weaknesses. Finally, the broader implications for policy makers, as well as, private sector actors are discussed, in addition to future research needs.

1.1. Forest carbon accounting

The first component of TEV herein concerns forest carbon accounting, since, as previously mentioned, carbon markets are established markets and almost always a part of voluntary measures. Furthermore, carbon storage and climate benefits of forests are among the most popularly studied (Egoh et al., 2012; Martínez-Harms and Balvanera, 2012). Land use choices will impact the environmental quality of the surrounding region, and, depending on the size and dynamics of an ecosystem, possibly on the continental and global scales (e.g., agriculture encroachment in the Amazon Rainforest). Forests (both by their biomass and soils) are a major mechanism of removing CO₂ from the atmosphere (following oceans) and will continue to be major carbon sinks, especially with regards to the uncertainty of oceans as future carbon sinks.

Currently, only a few afforestation and reforestation (AR) methodologies have been approved by the clean development mechanism (CDM) (UNFCCC, 2016), a policy instrument of the Kyoto Protocol whereby emission-reduction projects are certified in developing countries to be used by developing countries in order to meet their emission reduction targets. For carbon forest projects the 2006 IPCC Guidelines for National Greenhouse Gas Inventories offer a robust means of carbon accounting¹ (IPCC, 2006). The means for generic carbon accounting methods are detailed in volumes two (Aalde et al., 2006a) and for forest lands that will remain forests in volume four (Aalde et al., 2006b). There are three tiers. Each higher-level tier entails more sophisticated modeling, but requires more data. At tier one, a simple gain-loss method determines the difference between the five carbon pools found in a forest.

At tier one, carbon accounting may rely upon international forestry data provided to the International Panel on Climate Change (IPCC) by the United Nations (UN) Food and Agriculture Organization (FAO). So long as the change in biomass is not too large, the gain-loss method is sufficient for measuring carbon sequestration (Aalde et al., 2006b). However, when national data or more precise measurements are desired, tier two and three methods are recommended.

1.2. The ecosystem services approach

The second component of TEV in this study considers other ecosystem goods and services provided by forests. Just like carbon sequestration, other ES are understood as the benefits that human society draws (directly or indirectly) from the environment, which have been divided into several categories (MA, 2005). The benefits that ES represent are the result of ecosystem structures, processes, and functions, as illustrated by the cascade model of The Economics of Ecosystems and Biodiversity (TEEB Foundations 2010). These ES are often measured in biophysical terms either directly (especially for provisioning services) or indirectly via proxies (often for regulating services) (Bartelmus, 2015; Egoh et al., 2012), which can be transformed into monetary values via markets or environmental valuation methods. In the case of

cultural services, environmental valuation methods such as stated preference methods (contingent experiment or contingent valuation) or economic methods such as revealed preference methods (surrogate markets) are often employed (Bírol et al., 2006). Furthermore, using exchange valuation (extent to which something contributes to the economy) versus welfare valuation (extent to which something contributes to human welfare) will produce different results (Bartelmus, 2015; Remme et al., 2015).

Earlier (Costanza et al., 1997), but especially since the United Nations' Millennium Ecosystem Assessment (MA) report, initiatives began to attempt to quantify and/or map these ES (Martínez-Harms and Balvanera, 2012; Schägner et al., 2013). The new attempts in these studies often were frameworks that did not necessarily offer expressed values, but rather the means to perform ecosystem assessments (Baveye et al., 2013; Daily et al., 2009; Gómez-Baggethun et al., 2010; Maes et al., 2016). Bagstad et al. (2013) performed a literature review of 17 existing ES tools. Many require large data input, are region or scale specific, and a high degree of expertise. While the authors did not evaluate tools' complexities, they caution against over confidence in complex models and find that more complex models do not always perform better than simpler ones, especially for decision-making.

Mapping tools are linked with geographic information system (GIS) software that offers both greater complexity (overlay of models) and benefits from the visualization of ES distribution. While this type of software can process large amounts of primary data, land cover or use still remain popular as a proxy to determine ES and most studies focus on only one ES (Crossman et al., 2013; Schägner et al., 2013). The evaluation of provisional ES, which would appear easier, such as food or timber production, must differentiate between supply and actual demand, still a challenge which requires multiple methodologies (Rasmussen et al., 2016). Aside from provisioning services for which food production is almost always included, carbon storage is among the most popular ES studied (Crossman et al., 2013). Land use policy is the most common use for mapping ES and aside from multi-land cover, forests are the most popular study area (Schägner et al., 2013).

Some of the tools reviewed by Bagstad et al. (2013) include databases which offer the possibility to employ the value transfer method. According to the authors, the best maintained databases include the Environmental Valuation Reference Inventory (EVRI), the Marine Ecosystem Services Database, and The Economics of Ecosystems and Biodiversity (TEEB). The EVRI which draws from more than 4000 primary studies, however offers valuation of 6 kinds of ES and the Marine Ecosystem Services Database's focus does not extend to all biomes. The TEEB draws on a database of 1310 primary studies across 15 biomes for 22 ES and is considered a premiere in its field (Bagstad et al., 2013; Gómez-Baggethun et al., 2010; Villa et al., 2014).

TEEB (2010) continued the work of the MA (2005) and largely adopted its list of ecosystem services. However, unlike the MA, TEEB delineated the biophysical processes, structures, and functions that underlie the provision of ecosystem services and the benefits they bring to human populations. The delineation of this process led the authors to modify the MA framework by eliminating supporting services category, which consists of nutrient cycling and food web dynamics. These are contained in the first part of TEEB's cascade model, biophysical structures and processes of organisms in ecosystems that provided the necessary ecosystem functions that, when optimally operating, offer ecosystem services. The TEEB authors consider the MA's supporting services as a subset of ecological processes, and thus unnecessary. In its place, the authors have added the category Habitat services, which stresses the importance of ecosystems as areas of protection for migratory species and gene-pool hotspots that support the genetic biodiversity of species (De Groot et al., 2010).

Biodiversity influences all aspects of ecosystems (Mace et al., 2012) and its measurement requires further research (Kumar et al., 2010). The role of biodiversity differs per ES (Mace et al., 2012), and it acts as a regulator of ecosystem processes, which is intimately connected to their

¹ Carbon accounting here is defined according to Stechemesser and Guenther (2012, p.36) as "the recognition, the non-monetary and monetary evaluation and the monitoring of greenhouse gas emissions on all levels of the value chain and the recognition, evaluation and monitoring of the effects of these emissions on the carbon cycle of ecosystems."

stability and resilience, as well as a good in itself. Methods for measurement of biodiversity tend to focus on variety among species and the presence of high trophic level species (Elmqvist et al., 2010), which fits into the goods category of Mace et al. (2012). Less clear is how to value the other categories like regulator and service in an ecosystems service approach.

Finally, analyzing the tradeoffs of multiple ES, a major objective of the field, entails different approaches. Most studies still operate within an, albeit extended, cost-benefit analysis (CBA) framework. Final valuation, monetary or otherwise, within a CBA framework offers a more universal conclusion, but does not show implicit tradeoffs or the criteria used to judge them (Saarikoski et al., 2016). Multi-criteria decision analysis (MCDA) methods provide a transparent and participatory means to evaluate ES tradeoffs and attempt to reach Pareto efficiency (Wam et al., 2016). When stakeholder conflict must be addressed or ES distribution is important, MCDA methodologies offer a remedy (Dawson and Martin, 2015; Lakerveld et al., 2015).

1.3. Regional added value

The third component of TEV to consider are socioeconomic aspects, such as added-value. From a purely economic point of view, added value is the sum of unit profit, unit depreciation cost, and unit labor cost (Mankiw, 2007). More broadly, added-value entails benefits a product brings aside from the profits or its utilitarian value, put simply, it means that the value of the product is greater than its combined inputs (CIPRA, 2006; Jörg, 2014).

In the context of forestry, the scale is regional. Thus, an emerging concept in the literature is regional added value (RAV). It shares many aspects of socio-economics and sustainable development. It attempts to account for the development of regional autonomy, greater public participation in regional decision-making, preservation and reinforcement of regional identity and local initiatives (Hoffmann, 2009; Mühlinghaus and Wälty, 2001; UNIDO, 2010), regional financing options enhancing participation of regional stakeholders, and regional value chains, alongside more traditional aspects of regional development such as the creation of industry and employment. Region can be defined along administrative or geographic lines, but can also be defined by the homogeneity of culture and or demographics located within a specific area (CIPRA, 2006).

This concept is illustrated in Figs. 1 and 2 using regional renewable energy as an example. In Fig. 1 the region does not use local renewable energy sources to generate heat and energy and instead must import energy in the form of oil (the material/energy flows arrow), which

results in an outflow of financial resource. However, in Fig. 2 the local renewable energy sources are utilized, which reduces the amount of imported energy and thus the amount of financial resources that leave the region. Instead, with investment (funds arrow), the local potentials result in the production of energy and generate revenue for local energy producers, which can cascade to supporting sectors (e.g., logistics and construction) resulting in more financial resources staying within the region.

Despite the fragmented nature of the RAV in the scientific literature, it is a popular concept in German institutions (Pietz, 2016). Hoffmann (2009) defines it simply as the net sustainable generation of benefits over the non-sustainable values incurred by an action. The Institute for Applied Material Flow Management (IfaS) emphasizes the valuation of additional values, the explicit temporal aspect of RAV, and inclusion of ecological, social, and ethical aspects (Pietz, 2016). Basic cost-benefit analysis (CBA) underlies the measurement of all of these definitions and as such they tend to emphasize the monetary aspects, since the measurement of ecological and social aspects in monetary terms is often difficult (Hoffmann, 2009). RAV, as it has been applied to local sustainable energy, tends to focus on regional value chains. Since such extensive value chains do not exist in the forestry sector, a RAV indicator system was identified from a literature review (Table 1). The indicators are grouped along direct benefits, indirect benefits, and costs. Their description and means identified for measuring these issues are listed as well.

2. Materials and methods

The objective of this work is to integrate carbon accounting, ecosystem services, and regional added-value of forests into a single value to measure their total economic value. Given the enormous challenge of combining such disparate values, the methodology created herein relies upon previously developed and tested methodologies. A literature review was conducted, which is detailed in Annex 1. The details of each of the three major parts of the equation will be further explained in methodological subsections 2.1, 2.2, and 2.3, here, the overall method is presented along with considerations particular to forestry. The adaptation of the IPCC guidelines (Aalde et al., 2006a) for the TGV is detailed in Annex 2. A step-by-step example of the TGV tool is explained in Annex 3. The method for developing the TGV tool can be visualized in Fig. 3.

IPCC: International Panel on Climate Change; RAV: regional added value; TEEB: The Economics of Ecosystems and Biodiversity; TGV: total green value

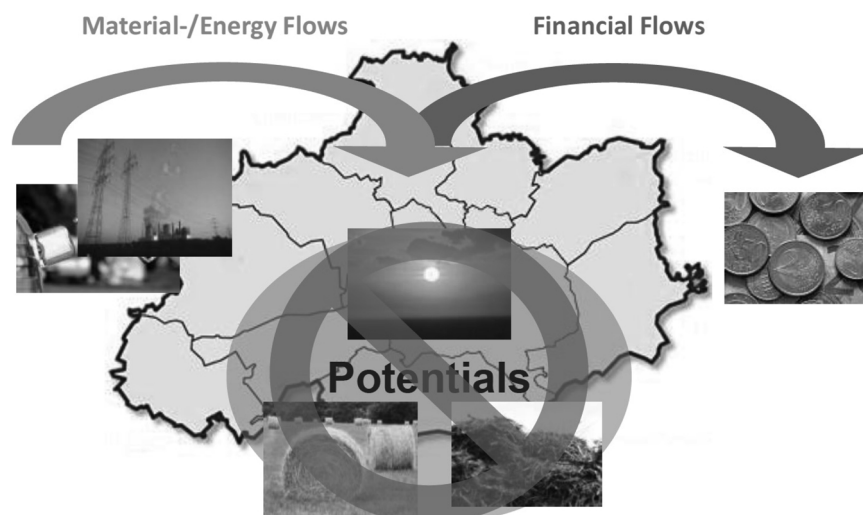


Fig. 1. Regional wasted renewable energy potentials (Pietz, 2016).

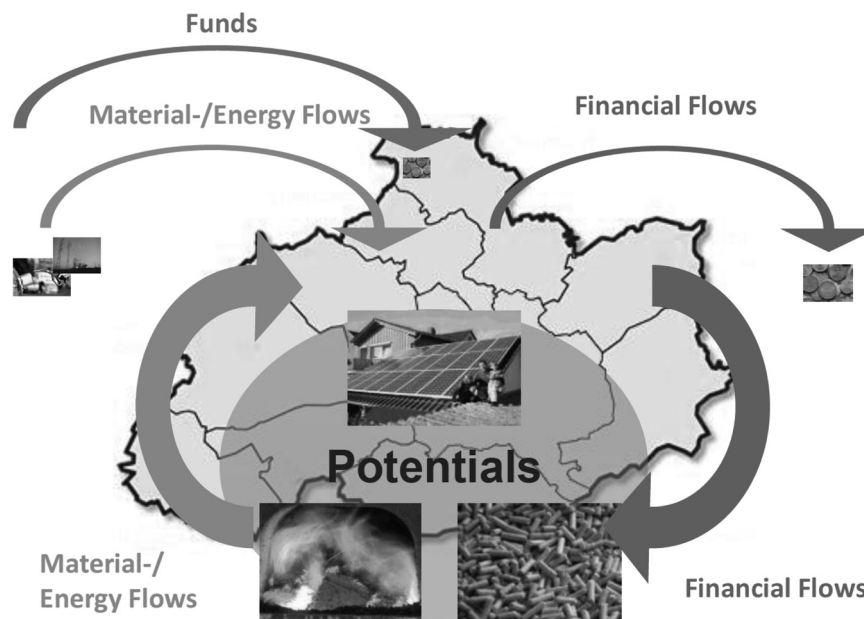


Fig. 2. Regional optimized renewable energy potentials (Pietz, 2016).

The product of this process of literature review, methodology selection and adaption is a spreadsheet tool. The overall method consists of three parts described in Eq. 1.

$$TGV = \sum Carbon_{sequestration} + \sum Ecosystem\ services + \sum RAV \quad (1)$$

Where:

TGV = total green value

$\Sigma Carbon_{sequestration}$ = sequestered net carbon

$\Sigma Ecosystem\ services$ = net ecosystem services

ΣRAV = net regional added value

Eq. 1 shows the final value, or the total green value (TGV) of a forest using this methodology. The methodology developed for this will be hereafter referred to as the TGV tool or simply the tool.

The sum of these three components will generate a single monetary value (€) for a given project that represents its TEV. Given the large amounts of data and calculations required, an electronic spreadsheet was employed (see supplementary material).

The definition of what constitutes a forest is important as different kinds of land use have different net balances of greenhouse gas emissions (GHGs), ES, and RAV. Here, the CDM defines a forest as an area of land (minimum 0.05 to 1 ha) with tree crown cover (minimum 10–30%) that has trees reaching two to five meters minimum at maturity (UNFCCC, 2016). The data and calculations used in the TGV tool are for natural forests (as opposed to plantations, afforestation, or reforestation) at least 20 years old that will remain forests (as opposed to converting from or to a different kind of land use). The actual area, in hectare (ha), of the forest that a project will cover must be defined and verified on a per project basis. Use of official (local or national) administrative maps is encouraged. This is important given that the carbon sequestration and ES calculated in the TGV tool are done so on a per hectare and per year basis.

The project's life cycle must be made explicit as this will have major consequences for calculating its net present value (NPV). A controversial part of calculating the NPV is choosing the discount rate (Hoel and Sterner, 2007). Fundamentally there are private and social discount rates. The former is used by private companies to calculate the cost of capital. The latter are used for projects and policies that impact society at large that reflect society's time preference for deriving benefits from a given project, which would be the case for NPAs. Since there are no strict economical guidelines for choosing a discount rate, a simple 4% is used since it is a popular social discount rate in the

literature (Guo et al., 2006; Kumar et al., 2010). However, for a given project, different rates or kinds of discount rates (e.g., declining discount rate), as well as, local circumstances (e.g., local bond rates, country risk, inflation rate) may be considered.

Another consideration in the TGV tool is the price of carbon. The default price in the tool is that of the European Union's (EU) emission trading system (ETS), the first emissions trading scheme and the largest (World Bank et al., 2016). However, this can be changed based upon the location of the project. Furthermore, given the challenges of carbon pricing in the EU ETS, a project may set a different price based upon different methodologies, but such considerations are beyond the scope of this work. The first component of the TGV tool is carbon sequestration.

2.1. Carbon sequestration accounting methodology

The carbon sequestration of forests is a controversial topic (van der Gaast et al., 2016). The IPCC's "2006 IPCC Guidelines for National Greenhouse Gas Inventories" was chosen since it had methodologies and data available for forest land that was natural and would remain forest land (IPCC, 2006). Given local data requirements of tier 2 and 3, the tier 1 level methodology was employed (Table 2), and calculation steps are detailed in Annex 2.

The sequestered total carbon for the current time period and future periods is given per hectare. Multiplying these by the area of the forest project gives tonnes of carbon. This is then multiplied by the market prices of any carbon trading scheme to yield a final value (€) for total carbon sequestered. For the TGV, the value per tonne of carbon used is equivalent to the price of an EU Allowance Unit (EUA) at close on September 15, 2017 (6.95 €/t/CO₂e²). The next component in the TGV tool is to calculate the total value of ES provided by a forest on a per hectare basis.

2.2. Ecosystem services methodology

Given the need to develop a methodology that could be readily applied to different contexts, the benefits transfer methodology for

² Data found at <https://www.investing.com/commodities/carbon-emissions-historical-data> and <https://carbon-pulse.com/category/eu-ets/>.

Table 1
Regional added value indicators.

Socio-economic values		Description	Indicator(s)	Reference
Direct benefits	Employment	The number of jobs and their duration generated throughout the project's lifecycle	Job years (number of jobs multiplied by their duration)	(Weisbrod and Weisbrod, 1997)
	Income/wages	The income and wages generated throughout the project's lifecycle for the local population	Total income (€)	(Weisbrod and Weisbrod, 1997)
	Regional taxes	Taxable income of the project	Taxable revenue	(Bess and Ambargis, 2011; Taks et al., 2011; Weisbrod and Weisbrod, 1997)
	Company profits (after tax)	The after-tax revenues of companies implementing the project(s)	Calculation of company profits with applicable taxes	(Bess and Ambargis, 2011; Taks et al., 2011; Weisbrod and Weisbrod, 1997)
	Regional autonomy	Reduce/replace regional imports, produce exports profiting local population (e.g. endogenous energy)	Products and services of specific project (e.g. tons of harvested wood; MW of electricity produced) that replace imports	(Mühlinghaus and Wälty, 2001)
Indirect benefits	Platform creation	Promotes informal and cross-sector networking, cooperation, and clustering among local stakeholders	The creation of formal and informal regional organizations	(CIPRA, 2006)
	Energy efficiency and savings	Reduced energy costs	Baseline and new or adjusted energy costs in Euros per year (€/a) in households, buildings, etc.	(Brunner and Rechberger, 2004)
	Waste prevention, reduction, reuse, and recycling	Difference between baseline generated solid waste generated and reduced solid waste generated	Baseline and new or adjusted waste generation (t/a) using municipality or waste company data	(Brunner and Rechberger, 2004)
	Knowledge gains	Promote learning and marketable skills	Training program costs (€)	(GRI, 2016)
	Community acceptance	Local community evaluates the desire or acceptance for the project	Local community survey	(Shiau and Chuen-Yu, 2016)
	Sustainable tourism	Increases or creates tourism that is environmentally benign	Number of visitors	(Birol et al., 2006)
	Traditional culture and heritage	Supports traditional institutions	n/a	(CIPRA, 2006)
	Regional production	Stimulates production in regional companies	Revenues €) from products used as inputs of other companies	(Miller and Blair, 2009)
	Inductive infrastructure impacts	Helps maintain community infrastructure (e.g., banks, post-offices, schools)	n/a	(CIPRA, 2006)

n/a = not available.

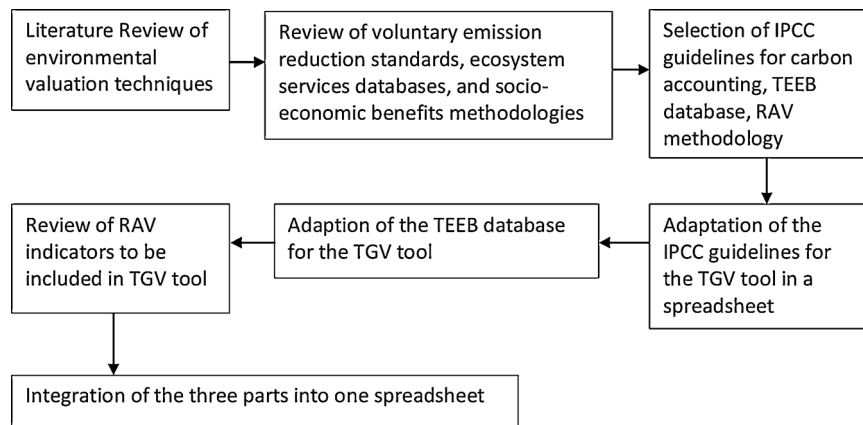


Fig. 3. Flowchart of the development of the TGV tool.

environmental valuation has been used. The TEEB database (Van der Ploeg et al., 2010) proved to have the most data points (1310) of any public database. Furthermore, it is considered one of the better maintained in the literature (Bagstad et al., 2013). The TEEB framework includes 22 ecosystem services categorized along provisioning, regulating, habitat, and cultural services (Table 3).

The TEEB database is available as a spreadsheet. It was filtered to include only data points that gave ES values on a per hectare and per year basis (1182 data points). The data was in 31 different currencies, so these were converted to international dollars using purchase price parity (PPP) as recommended and done for some values by the database authors (Van der Ploeg et al., 2010). PPP conversion rates from the Organisation for Economic-Cooperation and Development (OECD) database (2016) were applied to all values, except for those already in Euros or international dollars. Since individual data points used ranged from the years 1966 until 2010, US inflation was used to convert international dollars from earlier years to the PPP of international dollars in January of 2016 (US DOL, 2016). Data points in Euros were converted to January 2016 Euros using Eurozone inflation (StatBureau, 2017). Next, international dollars were converted to Euros via a PPP conversion rate from the OECD (2016).

Once all values were in 2016 Euros, data was categorized by the 15 biomes, their corresponding ecosystems, and ES data points available. In order to avoid double-counting, the climate ES (which entails carbon sequestration) was eliminated from forest ecosystems, and seven ES were moved to the RAV part of the TGV tool since they are socioeconomic in nature. For ecosystems that had multiple data points of the same ES, the average of these values was calculated. Finally, the values of the various ES for a given ecosystem were summed, similarly to the method performed by Costanza et al. (2006) in their valuation of New Jersey's ES in the US. The TEEB database also had values for general provisional services, general regulating services, TEV, and various ES,

these were not included in the sum of ES to avoid double-counting. The total gives ES values on a per hectare per year basis in 2016 Euros. The final component of the TGV tool calculates the RAV of a forest project.

2.3. Regional added value methodology

RAV is a recent term in scientific literature that is prevalent in Germanic literature and studies. The objective of this work with regard to socioeconomic valuation was to identify a methodology that captured the benefits and costs of forest preservation would bring to a region's social and economic dynamics.

A list of socioeconomic indicators found in the literature was compiled (Table 1), which was incorporated into the TGV tool. Indicators capable of being represented in monetary values and relevant to forest preservation were highlighted. These indicators included direct benefits: income and wages of workers directly dependent on the forest (e.g., park rangers and tour guides) and taxes (if the land is privately owned). Indirect benefits highlighted were tourism, which could be measured by the number of visitors multiplied by a willingness to pay. Finally, three cost indicators were found: displaced regional employment, opportunity costs (if plans had already been developed for the area under consideration), and lost revenues from harvest (e.g., harvested wood products – HWP).

Aside from the seven socioeconomic ES taken from the TEEB database, RAV values must be generated on a per project basis. These TEEB data points included services such as aesthetic, cognitive, cultural service, inspiration, ornamental, recreation, spiritual. For a given project, should local data be used to calculate the RAV, once it is important not to double-count values such as recreation which considers tourism WTP monetary values. Values, as is the case with TEEB values, should be considered on a per annum basis.

Like much of the RAV literature (CIPRA, 2006; Hoffmann, 2009;

Table 2
IPCC methodology data requirements.

IPCC tier level	Data requirements per carbon pool	Strengths and weaknesses	Notes
Tier 1	FAO data	Data readily available for quick estimation, but does not account for disturbances of uncertainty. Carbon losses due to land conversion assumed to all occur in same year. Does not account for non-CO ₂ emissions.	Process models, e.g., gain-loss method, acceptable. Steady state for carbon pools assumed to be 20 years.
Tier 2	Country specific data.	National data requirements may not necessarily require sampling, offers more accurate calculations. Changes in biomass further disaggregated using process models for more accurate measurement.	Process models and stock-difference method acceptable, but requires that countries already have a national forest inventory.
Tier 3	Country specific data and measurements or modeling.	In addition to strengths and weaknesses listed in tier 2. More accurate models with greater certainty, but require periodic sampling over a longer time period. Can account for non-CO ₂ emissions.	Stock-difference method encouraged, but requires that countries already have a national forest inventory.

(Aalde et al., 2006a,b).

Table 3
TEEB framework ecosystem services.

Ecosystem service	Description	Indicator(s)	Reference
Provisioning services			
1 Food	Food extracted	Harvest and production rates	(Costanza et al., 1997; De Groot et al., 2010; MA, 2005)
2 Water	Fresh water	Reserves and flow rates; water area per ecosystem	(Costanza et al., 1997; De Groot et al., 2010; MA, 2005; Maes et al., 2016)
3 Raw materials	Raw materials (fibers)	Biomass stock; harvest rates;	(De Groot et al., 2010; MA, 2005; Maes et al., 2016)
4 Genetic resources (industrial products)	Variety and unique species produced	Product ingredients produced from ecosystem (market value)	(De Groot et al., 2010; MA, 2005)
5 Medicinal resources	Medical products	Medical components produced from ecosystem (market value)	(De Groot et al., 2010; MA, 2005)
6 Ornamental resources (fashion)	Resources for handcrafts and fashion	Products produced from ecosystem (market value)	(De Groot et al., 2010; MA, 2005)
Regulating services			
7 Air quality regulation	Filter air flows	Hectares of natural and semi-natural forest coverage	(Costanza et al., 1997; De Groot et al., 2010; MA, 2005; Martín-López et al., 2014)
8 Climate regulation	Sequestration of GHG	Hectares of natural and semi-natural forest coverage; NPP; pH levels (in marine ecosystems)	(Costanza et al., 1997; De Groot et al., 2010; MA, 2005; Martín-López et al., 2014)
9 Disturbance moderation (e.g., storm and flood protection)	Areas of ecosystems that mitigate the negative impacts from storms	Designated areas to protect infrastructure	(Costanza et al., 1997; De Groot et al., 2010; MA, 2005; Maes et al., 2016)
10 Regulation of water flows	Maintenance of hydrological cycle	Flow rates (m ³); forest area (designated to protect water resources); snow cover (m ²)	(Costanza et al., 1997; De Groot et al., 2010; MA, 2005)
11 Waste treatment	The filtration, sequestration, or absorption of wastes	Concentration of nutrients or pollutants (mg/L); ecosystem area (m ²)	(Costanza et al., 1997; De Groot et al., 2010; MA, 2005; Maes et al., 2016; Martín-López et al., 2014)
12 Erosion prevention	Maintenance of soil formation and composition	Soil loss in sedimentation (mm/a); forest area (m ²); number and density of hedgegrows	(Costanza et al., 1997; De Groot et al., 2010; MA, 2005; Maes et al., 2016; Martín-López et al., 2014)
13 Nutrient cycling	Soil fertility maintenance	Organic matter in top soil	(Costanza et al., 1997; De Groot et al., 2010; MA, 2005)
14 Pollination	Pollination and seed dispersal by species of a given ecosystem	Pollination potential maps; number of pollinating species; area of dependent crops (m ²); honey production	(Costanza et al., 1997; De Groot et al., 2010; MA, 2005; Maes et al., 2016)
15 Biological control	Population control through trophic-dynamic relations	Number of species	(De Groot, Wilson, and Boumans 2002; De Groot et al., 2010)
Habitat services			
16 Nursery service	Lifecycle maintenance (nursery)	Species distribution	(De Groot et al., 2010; Maes et al., 2016)
17 Genetic diversity	Gene pool protection	–	(De Groot et al., 2010)
Cultural services			
18 Aesthetic	Scenery	Number of visitors; entrance fees	(Costanza et al., 1997; De Groot et al., 2010; MA, 2005)
19 Recreation	Tourism	Number of visitors; entrance fees	(Costanza et al., 1997; De Groot et al., 2010; MA, 2005; Martín-López et al., 2014)
20 Inspiration	Inspiration for culture, art, and design	Number of visitors	(Costanza et al., 1997; De Groot et al., 2010; MA, 2005)
21 Spiritual experience	Spiritual significance of a given ecosystem for a particular culture	Number of visitors; number of sites	(De Groot et al., 2010)
22 Cognitive development	Educational and research opportunities	Number of visitors; number of publications	(De Groot et al., 2010; Maes et al., 2016)

Jörg, 2014; Pietz, 2016), the RAV methodology here follows a CBA calculation of subtracting the costs from the benefits to find the total RAV. For future time periods the costs and benefits of a forest project are assumed not to change.

3. Results

The result of the methodology employed in this work is the TGV tool in an electronic spreadsheet (see supplementary material), which integrated carbon sequestration, ecosystem services, and regional added value into one monetary value for natural forests projects. While this example was performed for a temperate continental forest, it is important to stress that the TGV tool is applicable to other forest ecosystem types included in both the IPCC guidelines (Aalde et al., 2006b) and the TEEB database (Van der Ploeg et al., 2010), e.g., tropical, subtropical, boreal, and other types of temperate forest ecosystems. This highlights its relevancy to policy makers globally. A step-by-step hypothetical example is described in Annex 3. This is followed by a discussion of the tool, in particular its implications for policy makers. This section concludes by discussing the limitations of the tool and

suggestions for further improvement.

3.1. Discussion

The TGV tool represents an ambitious attempt to capture the total value of forests for local communities. The tool helps to highlight and measure the non-direct benefits of forests that can benefit communities at all scales from local, to regional, to international. There are several implications that stem from its development: the appropriateness of environmental economics as a proper framework for addressing environmental challenges, the strengths and weaknesses of using monetary valuation, the relationship between science and policy, and the various levels of benefits the tool identifies. Furthermore, the simplicity in this tool offers quick estimations, which can lead to more widespread use of so-called “carbon plus” valuation, i.e., the inclusion of other ES and socioeconomic benefits.

Despite the ethical issues surrounding environmental economics, since it applies anthropocentric approaches to environmental problems, which inherently involve more than human populations, it demonstrates its practicality. The MA (2005) identified the severity of

ecosystem degradation, and if the command-and-control policies of the late 20th Century offer any lessons, it is that policies and actions that fail to communicate and integrate themselves sufficiently into stakeholder decision-making will not be effective in reversing such environmental devastation. Despite the challenges for many environmental valuation methods over their history (Baveye et al., 2013), environmental service valuation provides valuable information to decision-makers by explicitly illustrating trade-offs (Costanza et al., 2014).

An objective of this work was to integrate these three aspects of forest valuation (carbon sequestration, ES, and RAV) into one final value. Monetary valuation is easily cognizable by most any community, but diminishes the richness of qualitative benefits, as evidenced in the RAV table. It is important to highlight that monetary valuation is not privatization of these ES, nor can the sequestered carbon be traded (Costanza et al., 2014). Rather, such sequestered carbon must be seen as retired carbon, unless sustainable forest harvesting takes place, which this tool does not address. That which is not measured cannot be appropriately valued, TEV aims to address the “hidden” values of ecosystems.

The tool offers a bridge between science and policy, in this case forest conservation and regional planning. A major challenge identified in the literature is the lack of agreement about terms and standards (Nahlik et al., 2012), this tool helps overcome this fragmentation precisely due the reputations of the methodologies employed. The roles of scientists in assisting policy makers will vary according to the complexity of the problem, but Spruijt et al. (2014), in a literature review of the subject, find that scientists should present humility in their advice, integrate different forms of knowledge better (e.g., academic, experiential), explain different viewpoints in their respective field, encourage public participation, and interaction among stakeholders. The TGV tool offers a means of communicating the values of forests to a large audience. This is supported in the literature, which finds that the valuation and quantification of ES helps integrate their consideration into decision-making (Daily et al., 2009).

The value of forest conservation brings benefits and values at the regional, national, and international levels. The immediate regional benefits of forests can be seen in their ecosystem services and regional added value. These benefits are economic, social, and ecological. Often ES provide support to regional economic activities such as soil protection and water filtration. On the national and international level, the carbon sinks that forests represent help countries improve and maintain air quality, as well as, capture and store carbon-dioxide emissions.

Finally, the TGV offers policymakers a tool with preset international data to quickly assess and estimate tradeoffs surrounding land use decisions regarding forests. While this tool does not replace ecosystem assessment, nor was this its aim, it can help integrate such ecosystem services thinking into internal decision-making by providing value estimates with minimal local data. Furthermore, the TGV spreadsheet is user friendly and does not require special training. The international data averages provide estimates of the ES values based upon multiple case studies. Taking these aspects together, a land use planner will better understand potential costs and benefits of a given area of forest before committing to a decision.

3.2. Limitations

The TGV tool represents a step towards providing the TGV of forest preservation, but it has several limitations that must be observed. First, the literature is filled with cautions against using single values in ecosystem valuation as these can inspire overconfidence in the preciseness of measurement and often undervalue ES (Bagstad et al., 2013; Baveye et al., 2013; De Groot et al., 2010; Dlamini, 2012; Farber et al., 2002; Martín-López et al., 2014; Turner et al., 2010). Nevertheless, this also represents a strength of the tool in its capability to communicate TEV of forests to policymakers in monetary terms.

Regarding the carbon sequestration component of the TGV tool several limitations require mentioning. First, the data used here is international and as with any such method, this will not be able to compete with local assessment. Due to this limitation, tier one IPCC methodology is used, which offers a simple gain-loss method to accounting carbon sequestration. Furthermore, this leads to the carbon sink of a defined forest area growing over time as data for losses from disturbances are not readily available. However, the growth of carbon stocks in European forests from 1990 to 2010 tends to broadly support this approach (Pülzl et al., 2013). Thus, any implementation of this tool must search for available data regarding forest fires and biomass losses from insects to refine the calculations.

Considering the ES portion of this tool, numerous limitations stem from the complexity of the endeavor. First, this tool is based on international databases and a literature review, but not connected to any kind of GIS software. While in the case of ES more advanced tools do not necessarily perform better than simpler databases (Bagstad et al., 2013), GIS software can help model actual spatial flows of ES, which the TGV tool cannot. This tool, like many found in the literature, assumes linear flows of ES and does not address thresholds (Villa et al., 2014). So the quality of ES is assumed to be the same for a forest of one hectare or 500 ha. In the case of smaller forest projects, this must be met with caution as the monetary value of ES would likely rise, but their quality and flow would likely fall (Spash, 2008). The TGV tool does not account for the economic context, which has shown to influence valuation methods such as WTP (Birol et al., 2006). Using the TEEB database provides a wealth of studies, but for any given ecosystem, the 22 ES in the TEEB framework (or the 14 used in the TGV tool for ES, the climate ES has been removed to avoid double-counting, and seven are used for RAV) are rarely all present. Furthermore, for any specific ES, valuation studies are limited in number which leads to higher variance in values. This simply requires more studies to provide more data. Considering the summation of ES, which is a common method in the literature (Costanza et al., 1997, 2006), this method does not address competitive ES.

An important goal of environmental conservation and ecosystem service valuation is the enhanced protection of biodiversity (Reyers et al., 2012). The measurement and quantification of biodiversity in ES valuation has proven to be a consistent challenge (Mace et al., 2012). Consideration of biodiversity is inherent in ES such as the regulating service – biological control and the habitat services – nursery and genetic diversity. Furthermore, biodiversity is often considered to underpin the flow and quality of all ES through concepts such as resilience and ES portfolios (Kumar et al., 2010). The TGV tool offers few criteria for assessing the level and quality of biodiversity protection between two forest projects other than projects' size and, in the case of different forest types, possibly different varieties and quantities of ES. To put a final price on the level of biodiversity would require knowledge of the quality and flow of ES.

While biodiversity is not explicitly valued in the TGV tool, its various ecosystem roles (e.g. regulator, multiplier of ES, and good) are inherent in many of the ES utilized in the TEEB concept. Due to climate change, the future ability of forests to sequester carbon is uncertain. Second, increasing climatic pressures on forests might degrade the ES they provide. Increased vulnerability to natural disturbances could diminish their socioeconomic benefits. Underlying all three aspects is the resiliency that biodiversity provides to the structures underlying the provision of these services.

In line with the aims of this project, RAV was identified as an appropriate method for measuring the socioeconomic benefits of forest conservation. The literature, outside of Germany, is scarce in terms of this methodology's elaboration. Further development of the concept's definition and application to sectors outside bioenergy is necessary. Value chain analysis is the dominant method among RAV studies that attempt to qualify socioeconomic benefits. Unlike the other two components of the TGV tool, there are no readily available databases

assessing socioeconomic values.

The RAV component of the TGV tool offers few readily available data points. An objective of this work was to develop an integrative method that balanced precision and ease of application, the latter part of this is curtailed in the RAV component as more accurate RAV valuation of a forest project will require extensive contributions by local data and stakeholders. Application of RAV to forest conservation proves a challenge, since most RAV studies involve manmade products and services, thus a value chain methodology is limited to indicators in this case.

4. Conclusions

The TGV tool aims to balance ease of application and scientific rigor, so that it can be quickly applied to assist decision-makers concerning the benefits a region draws from a forest.

Explicit valuation highlights the tradeoffs existing in planning, policy, program, and project scenarios. Market-based policies offer a means of incorporating externalities into public and private decision-making. Voluntary policies that are the initiatives of both state and non-state actors often precede mandatory requirements - carbon offset markets are one such example. One means of this integration is the monetary valuation of social and ecological benefits, which proves to be a methodological challenge. The strength of one single value is its clear communication of benefits and tradeoffs involved in certain ecosystem management styles. A weakness of this approach is the loss of information.

This tool offers policy makers a ready method for quickly assessing

the TEV of forests in their region. While it cannot replace site ecosystem assessments, the method is much more user friendly and less costly to implement and therefore offers an estimation that can easily be imbedded in preliminary decision-making regarding land use decisions. The tool could be further developed to include other land use types, such as agriculture, wetlands, and grasslands, and the impacts of land use change to expand possible areas of application. Implications of IPCC's climate change scenarios could also be incorporated into its further development. It offers an additional means of demonstrating that climate change and nature conservation are not at odds with regional development.

Conflicts of interest

The authors have no conflicts of interest.

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Annex 1 Literature review details

Carbon accounting literature review

The methodology for this work consisted of a literature review of methods and standards searching both scientific literature databases and grey literature. Grey literature consists of documents, reports, white papers, etc. of reputable institutions such as think tanks and other nongovernmental organizations (NGOs). The scientific literature databases consisted of Science Direct, Scopus, and Web of Science. Search terms included "accounting," "carbon," "CDM," "clean development mechanism," "established," "forestry," "greenhouse gas," "inventory," "methodology," "methodologies," "recognized," "reporting," "standards," "tool," and "voluntary."

Ecosystem services literature review

Just as for carbon sequestration, a literature review of scientific and grey literature was performed. The following keywords served as the basis for the search: "database," "established," "ecosystem," "environmental," "forest," "forestry," "mapping," "method," "methodology," "service," "tool," and "valuation."

Socioeconomic literature review

Just as for the other two components, a literature review of scientific and grey literature was performed. The following keywords served as the basis for the search: "database," "method," "methodology," "regional added value," "regional value added," "sustainable development," "sustainable regional development," "tool," "valuation," and "value added."

Annex 2 T1 IPCC

As mentioned previously, a tier one methodology was used in this work. Tier two and three methodologies are described in the IPCC guidelines, but require national or site data, which by definition of this tool are not available. In order to determine the net carbon sequestration of a forest, the "gain-loss method" of the guidelines was used (Eq. 2).

$$\Delta C_B = \Delta C_G - \Delta C_L \quad (2)$$

Where:

ΔC_B = annual change in carbon stocks in biomass (tonnes C a⁻¹)

ΔC_G = annual increase in carbon stocks due to biomass growth (tonnes C a⁻¹)

ΔC_L = annual decrease in carbon stocks due to biomass loss (tonnes C a⁻¹)

The functions ΔC_G and ΔC_L in Eq. 1 account for the carbon pools found in forests (above-ground biomass, below-ground biomass, litter and deadwood, and soil) following tier one methodology. Data used for calculations of carbon stocks can be found in volumes two (Aalde et al. 2006a) and four (Aalde et al. 2006b).

The calculation of the carbon stock and carbon stock growth of a forest consisted of calculating above-ground biomass on a per hectare basis, calculating the below-ground biomass on a per hectare basis, using Eq. 2 to calculate the average annual growth in above-ground and below-ground biomass on a per hectare basis, calculating the carbon stock of litter and deadwood on a per hectare basis, and finally calculating the soil carbon stock on a per hectare basis. The calculation of above-ground biomass on per hectare basis entailed using data from the guidelines that gave average values of above ground biomass (tonnes d.m. ha⁻¹) per climate domain (tropical, subtropical, temperate, and boreal) as well as various ecological zones for each climate domain. In order to calculate the below-ground biomass, for any given value of average above-ground biomass (e.g., climate

domain: temperate and ecological zone: temperate continental forest, 120 tonnes d.m. ha⁻¹) it is multiplied by the average ratio of below-ground to above-ground biomass found in the IPCC guidelines (e.g., ecological zone: temperate oceanic forest, continental forest, and mountain systems with above-ground biomass range of 50–100 tonnes, R = 0.29). The sum of these two numbers yields the first value for carbon stock calculated in the TGV tool.

Next, the average annual growth in above-ground and below-ground biomass on a per hectare basis is calculated via the equations Eqs. 3 and 4.

$$\Delta C_G = A \cdot G_{Total} \quad \Delta CG = A \cdot G_{Total} \cdot CF \quad (3)$$

Where:

ΔC_G = annual increase in carbon stocks due to biomass growth (tonnes C a⁻¹)

A = area of forest (ha)

G_{Total} = average annual biomass growth above- and below-ground (tonnes d.m. ha⁻¹ a⁻¹)

$$G_{Total} = GW \cdot (1 + R) \quad (4)$$

Where:

GW = average annual above-ground biomass growth (tonnes d.m. ha⁻¹)

R = ratio of below-ground biomass to above-ground biomass (tonne d.m.)

The carbon stocks found in litter and deadwood as well as soil types (tonnes of C in 0–30 cm) are listed in the IPCC Guidelines (2006). For tier one methods, the carbon stock of litter and deadwood is assumed to be in equilibrium, thus, no growth or loss is assumed.

The calculation of carbon stock loss in the TGV tool consists of calculating emissions from soils on a per hectare basis and biomass losses from disturbances. Average emissions for drained organic soils are given in the IPCC guidelines per climate domain (e.g., tropical, temperate, and boreal). Biomass losses from disturbances pertain to forest fires and losses from insects. Since harvested wood products (HWP) are not included, Eq. 4 below follows the guidelines advice for tier one methods that all emissions from disturbances are considered emitted in the same year.

$$L_{Disturbance} = A_{Disturbance} \cdot BW \cdot (1 + R) \cdot CF \cdot fd \quad (5)$$

Where:

$L_{Disturbance}$ = annual losses of carbon (tonnes C)

$A_{Disturbance}$ = area affected by disturbances (ha)

BW = average above-ground biomass of land areas affected by disturbances, (tonnes d.m. ha⁻¹)

R = ratio of below-ground biomass to above-ground biomass (tonne d.m.)

fd = fraction of biomass lost in disturbance

The fraction of biomass lost in a disturbance in tier one methodology is assumed to be one. Neither the IPCC Guidelines (2006), nor the supplementary guidelines (IPCC 2013) provide average values readily applicable, and these must be provided on a per project basis.

The total carbon sequestered per year then is the sum of the combined above-ground and below ground biomass, the carbon in litter and deadwood, and the carbon held by the soil. Subtracted from this sum are soil carbon emissions and losses from disturbances. For the calculation of NPV, future flows of carbon sequestration must be considered. For the future periods of above-ground and below-ground biomass totals, the net growth of carbon sequestration, taking the difference between the growth rate of above-ground and below-ground biomass sequestered (Eq. 2) and losses from disturbances (Eq. 4), is added. The litter and deadwood carbon pool is considered in equilibrium and therefore does not change over time. Losses of carbon from soil emissions are considered as constant and do not increase or decrease over time.

The total carbon sequestered for the current time period is on a per hectare basis, multiplying this by the area of the forest project gives tonnes of carbon. This is then multiplied by the current price found in the EU ETS to yield a final value (€) for total carbon sequestered. At close on September 15, 2017 the price of an EU Allowance Unit (EUA) was 6.95 €/t/CO₂eq³. The next component in the TGV tool is to calculate the total value of ES provided by a forest on a per hectare basis.

Annex 3 The Total Green Value Tool

The TGV tool was designed to allow a user to quickly assess the TGV of preserving a given forest. When opening the tool there are a series of tabs. The most important is called the “cockpit” tab from which all major input parameters and final values are controlled. There are also tabs for Carbon, TEEB database tabs, RAV, and currencies tabs. This section will briefly outline the steps to find the value of a forest.

Beginning with the cockpit tab, notice the legend in the upper left-hand corner, green cells mean they can be manipulated, while grey cells should not be changed as they contain formulas and values that calculations rely upon. The final TGV for current year of the forest will be shown in cell B2 and the three components final values are shown in cells B5–B7. To the right of the final present values are NPVs of the final values for five, 10, and 20 year time horizons. The project characteristics are displayed in A10–A12, inputs should be defined by the user in cells B10–B12. These include projects characteristics such as the discount rate, forest area, and price of carbon. For this example, the discount rate is 4%, the area is one hectare, and the price of carbon is based upon the price of carbon emissions in the EU ETS as of September 15, 2017 (6.95 €/t/CO₂eq). Cells B16–B21 show the final values for the carbon stock sequestered by carbon pool.

The input parameters for the three components of the TGV tool can be found on the cockpit tab from cells A24–E46. Beginning with ES, select the biome in B24 from the dropdown list (e.g., “Forests_Temperate_Boreal_TEEB”). This will present a specified dropdown list in C24 for ecosystem (e.g., “Temperate_forest_general_TEEB_E”). Finally ecosystems can be selected individually or the sum of the ecosystems can be selected by “All.” This will yield a € value on a per hectare per annum basis.

Next, the components for the carbon sequestration must be input. In cell B29 select the ecological zone, which should correspond with the ecosystem selected for the ES (e.g., “Temperate continental forest”). This will display the average above-ground biomass in natural forests (i.e., 120 tonnes d.m. ha⁻¹). Next, to determine the average annual above-ground biomass growth, select the ecological zone in cell B31 (e.g., “Temperate continental forest”), which will display a value in C31 (e.g., 4 tonnes d.m. ha⁻¹). Next determine the below-ground to above-ground biomass by

³ Data found at <https://www.investing.com/commodities/carbon-emissions-historical-data> and <https://carbon-pulse.com/category/eu-ets/>.

selecting the appropriate ecological zone. In this example “Temperate_oceanic_forest_continental_forest_mountain_systems.” Then select the appropriate above-ground biomass, keeping in mind the value displayed for the average above-ground biomass in natural forests displayed cell C29. In this example an acceptable value to select in cell C33 would be “conifers above-ground biomass 50–150 tonnes,” since the average above-ground biomass of 120 tonnes d.m. ha⁻¹ is within this range. The value is displayed in D33, for this example 0.29. In order to determine the soil emissions factor choose the appropriate climate, in this example “Temperate,” which has a value of 0.68 tonnes C ha⁻¹ yr⁻¹ displayed in cell C35. Determine the carbon stored in litter and deadwood by selecting an acceptable climate in cell B37, in this example “Cold_Temperate_moist22” was selected. Next, select one of two forest types in cell C37, in this example “Needleleaf evergreen” was selected. The value in this case is 26 tonnes C ha⁻¹ displayed in cell D37. Next, determine the amount of carbon stored in the soil by selecting an acceptable climate in the dropdown list in cell B39, for this example, “Cold_Temperate_moist23” was selected. Next, select one of six soil types in cell C39. The soil types include: high activity clay (HAC), low activity clay (LAC), sandy soils, spodic soils, volcanic soils, and wetland soils. For more information on these soil types see Table 2 in the carbon tab of the TGV tool or Table 2 in volume two of the IPCC Guidelines (Aalde et al., 2006b). For this example the “HAC” type was chosen. Next, determine the carbon fraction (CF) by choosing an acceptable climate value from the dropdown list in cell B41, in this example “Temperate_and_Boreal43” was selected. Then select the type of tree from the dropdown list in cell C41, “Temperate and Boreal Conifers” was selected in this example. The CF is displayed in cell D41. For the final step of the carbon sequestration component, determine the carbon losses due to disturbances. There are no preset data available here, so national or regional databases for a project must be consulted. The parameters needs include the annual area affected in hectares and average above-ground biomass in tonnes d.m. ha⁻¹.

The third component of the TGV tool, RAV is determined by selecting the corresponding biome (cell B46) and ecosystem (cell C46), the same as for the ES. In cell D46, a dropdown list of socioeconomic values is provided, in this example the sum of “All” values is selected. As mentioned in the method section, seven ES from the TEEB data base were moved to the RAV component since they are socioeconomic in nature, however, the user is encouraged to search for local RAV data and put that into the RAV tab. The table in the RAV tab of the spreadsheet also offers suggestions for where or how to go about finding the necessary data.

The other tabs of the spreadsheet include Carbon, front, Introduction, Variables, TEEB database, TEEB data, RAV, and Currencies. The Carbon tab has the data and tables used for the carbon sequestration calculations. The tabs from “front” to “TEEB_Data” include information used for the ES calculations. The original TEEB data base is found in the tab with the corresponding name. The data used for ES in the TGV tool can be found in the TEEB_Data tab and therefore should not be modified. The RAV tab can be modified should project specific data be available. Finally, the currencies tab involves the currency conversions for ES described in the method section and should not be modified.

From the above example for a hectare of temperate forest the TGV tool yields a value of 199,492.17 €/a. This large value stems mostly from RAV contribution and the recreation service (193,988.53 €/a). The carbon sequestration value is 1,912.08 €/a and ES values total 3,589.24 €/a. The yearly recreation value in daily terms is approximately 530 € per hectare. If a 25 ha forest were considered and an average family spent 100 € in total (considering travel costs, food, and time) to arrive at the park, this would mean 132 different visits per day. This is a modest number, since according to the US National Park Service (2017) the daily average number of visitors to the Yellowstone National Park is 8185. The value of carbon sequestration will be heavily influence by the price of carbon. The ES value is likely conservative, since the number of ES considered in this example is nine.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.landusepol.2019.03.018>.

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